Part I: Expansion, Distance, and Velocity

Consider the small section of the universe containing four galaxies (A–D), shown in Figure 1 below. The distances between each galaxy are also shown.

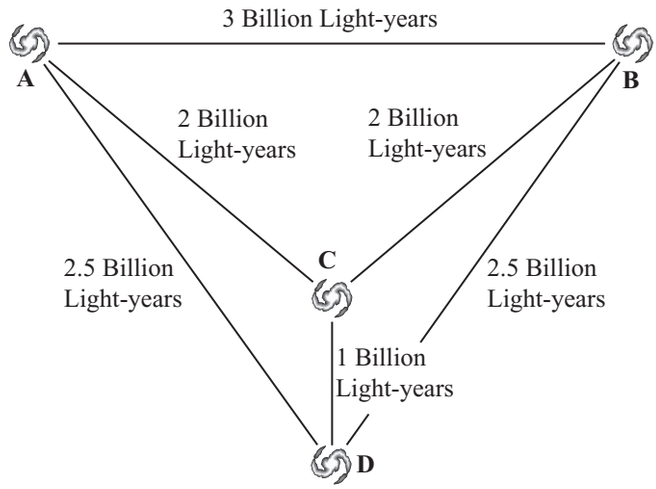

Figure 1

1) Imagine that this section of the universe doubles in size over time due to the expansion of the universe. Draw what the above section of the universe would look like after it doubles in size. Be sure to identify the new distances between the galaxies.

2) Which of the galaxies (B–D) increased its distance from Galaxy A by the greatest number of light-years during this time? Explain your reasoning.

3) Two students are discussing their answers to Question 2:

Student 1: *All of the distances doubled, so all of the distances increased by the same amount. There is no one galaxy whose distance from Galaxy A increased the most.*

Student 2: *You're right that all the distances double in size, but I don't agree that they all increase by the same number of light-years. Since Galaxy B was the farthest away from Galaxy A initially, its distance will increase by the greatest number of light-years when this section of the universe doubles in size.*

Do you agree or disagree with either or both of the students? Explain your reasoning.

4) Describe the relationship between a galaxy's distance from Galaxy A and the speed at which that galaxy appears to be moving away from Galaxy A.

5) Is the relationship you described in Question 4 unique to Galaxy A, or would you observe the same relationship (between distance and speed) if you lived in one of the other galaxies? Explain your reasoning.

Part II: Understanding Hubble's Law and Hubble Plots

The relationship you described in Questions 4 and 5 is called *Hubble's law*. We can depict Hubble's law with the graph shown at right. This graph plots the speed at which a galaxy appears to move away from us versus its distance from us. This type of graph is called a *Hubble plot*. Each dot on the plot represents a different galaxy.

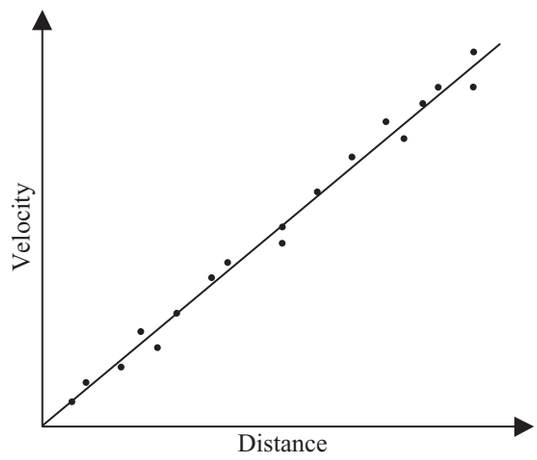

Figure 2

6) Explain how the Hubble plot shown in Figure 2 is consistent with the relationship you described in Question 4.

7) Imagine the Hubble plot shown in Figure 2 represents a universe that doubles in size over a certain amount of time. Which of the Hubble plots shown in Figures 3 and 4 below might represent a universe that triples in size over the same amount of time? Explain your reasoning.

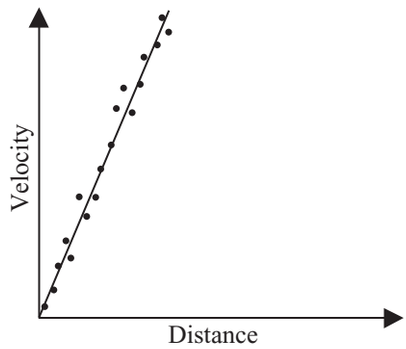

Figure 3

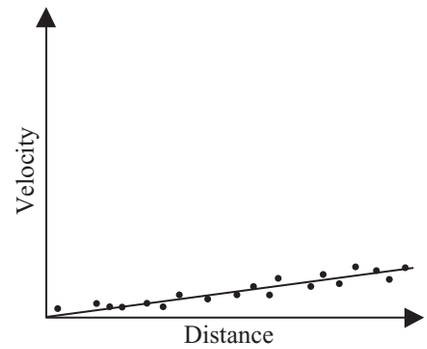

Figure 4

The *expansion rate* of the universe determines how fast the universe increases in size with time. For example, a universe that is tripling in size has a faster *expansion rate* than a universe that is doubling in size over the same amount of time. In a Hubble plot, the *expansion rate* is indicated by the slope of the graph. A steep slope indicates a fast expansion rate, while a flat slope indicates a slow expansion rate.

8) Would you say the expansion rate for the universe represented in Figure 2 is constant, increasing, or decreasing with time? Explain your reasoning.

9) Rank (from fastest to slowest) the expansion rates of the three different universes represented in Figures 2, 3, and 4. Explain your reasoning.

10) If the expansion rate of our universe had been faster, would the universe have reached its current size earlier in its history or later? Explain your reasoning.

11) If the Hubble plots in Figures 2–4 represent three universes that are the same size, which Hubble plot belongs to the youngest universe? Explain your reasoning.

12) Complete the sentence below using the words provided in parentheses ().

For two universes that are the same size, the universe with the faster expansion rate must be _____(younger/older) than the universe with the slower expansion rate. The slope of the line in the Hubble plot of the _____ (younger/older) universe will be _____ (steeper/flatter).

We can imagine many different Hubble plots, which may or may not represent how galaxies move as a result of expansion.

13) On the blank graph in Figure 5 below, draw a Hubble plot for which the expansion rate is zero.

14) On the blank graph in Figure 6 below, draw a Hubble plot for which the expansion rate increases throughout the lifetime of the universe.

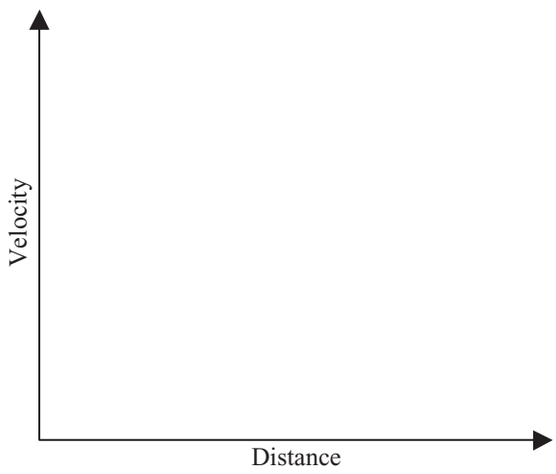

Figure 5

Figure 6

Part III: Our Universe

Recent observations indicate the Hubble plot for our universe actually looks more like the plot in Figure 7.

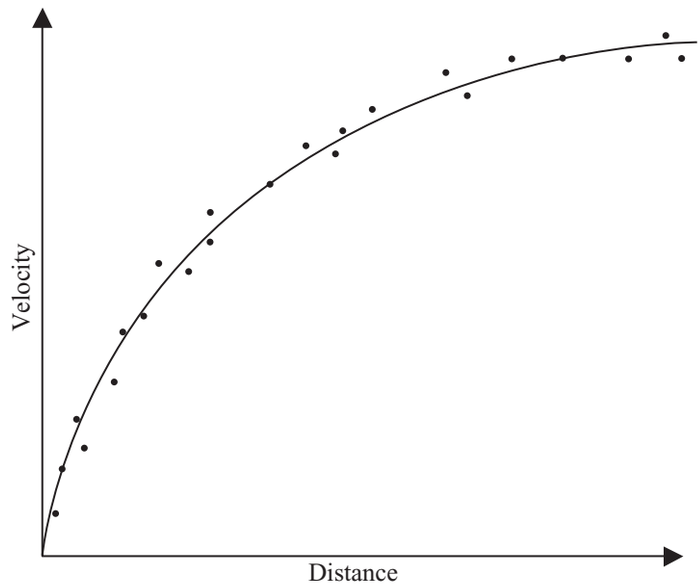

Figure 7

15) Parts a–h all refer to Figure 7. Draw or write the additional information on Figure 7 as instructed:

a) Draw a circle around the galaxies from which we receive light that was emitted closest to our present time.

b) Draw a square around the galaxies from which we receive light that was emitted furthest from our present time.

c) Write the letter C, and draw an arrow to the galaxies that are moving away from us with the fastest velocities.

d) Write the letter D, and draw an arrow to the galaxies that are moving away from us with the slowest velocities.

e) Write the letter E, and draw an arrow to the graph, where it has the steepest slope.

f) Write the letter F, and draw an arrow to the graph, where it has the flattest slope.

g) Write the letter G, and draw an arrow to the portion of the graph that corresponds to the fastest expansion rate.

h) Write the letter H, and draw an arrow to the portion of the graph that corresponds to the slowest expansion rate.

16) Based on the Hubble plot shown in Figure 7, would you say that the expansion rate of the universe is constant or changing with time? Explain your reasoning.

17) Based on the Hubble plot in. Figure 7, is the expansion rate represented by the motion of galaxies far away from us faster than, slower than, or the same as the expansion rate represented by the motions of nearby galaxies? Explain your reasoning.

18) Based on the Hubble plot in Figure 7, is the expansion rate of the universe increasing or decreasing as time goes on? Explain your reasoning.

19) Consider the following debate between two students regarding their answer to the previous question:

Student 1: *The expansion rate of our universe must be slowing down as time goes on. If you look at the Hubble plot, you can see that the graph gets flatter. That means the farther away you look, the slower the expansion rate is. The rate at which the most distant galaxies are moving away from us has started to slow down and eventually the expansion rate of nearby galaxies will also slow down.*

Student 2: *I think you are reading the graph wrong. The slope of the graph tells you how fast the expansion rate of the universe is, not how fast a galaxy is moving. The farther we look into space, the further we are looking back in time. Since the slope of the Hubble plot is flatter in the past and steeper now, that means the expansion rate has sped up over time.*

Do you agree or disagree with either or both of the students? Explain your reasoning.

20) Based upon your previous answers, is the graph you drew in Question 14 correct or does it need to be redrawn? Explain your reasoning.